W Helicity Measurement in Top Quark Decays at DØ

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OUTLINE:

- Introduction: Top Quark Production and Decay at the Tevatron.
- Measurement of the W Helicity.
- Outlook.

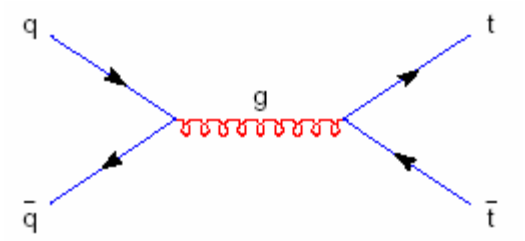
Top Quark Production and Decay

Large $m_t \Rightarrow$ probes physics at much higher energies than other fermions.

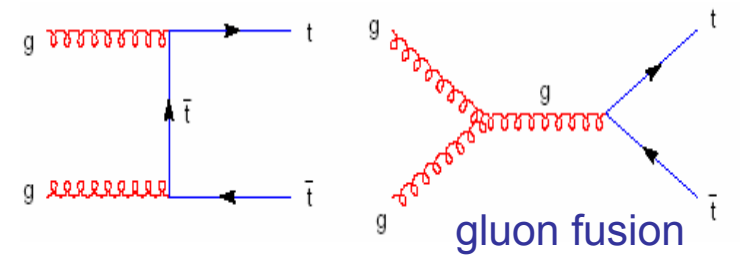
$m_t > m_W$, the W polarization in top decays is very different from that of other weak decays.

W helicity measurement is a test of the SM and an opportunity to look for new physics.

At the Tevatron $\sqrt{s}$ = 1.96 GeV, top quarks are primarily produced in pairs

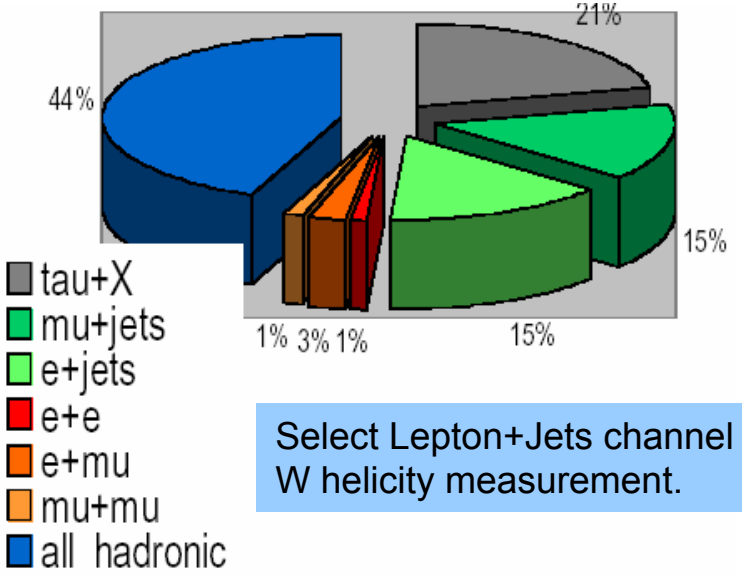


$q\bar{q}$ annihilation (85%)



gluon fusion (15%)

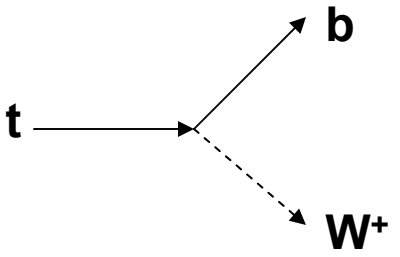
- Since $|V_{tb}| \sim 1$, the top quark almost always decays to Wb.
- Event topology depends on the W decay mode:
  - **Dilepton:** 2 high p_T leptons, 2 b-jets, large E_T^{mis}. BR(ee, μμ, eμ) = 5%.
  - **Lepton + Jets**: 1 high p_T lepton, 4jets (2 b-jets), large E_T^{mis}. BR(e,μ) = 30%.
  - **All hadronic**: 6 high p_T jets (2 b-jets). BR = 44%.



Select Lepton+Jets channel for W helicity measurement.

Weak Interaction of the Top Quark

V-A charged-current weak interaction:

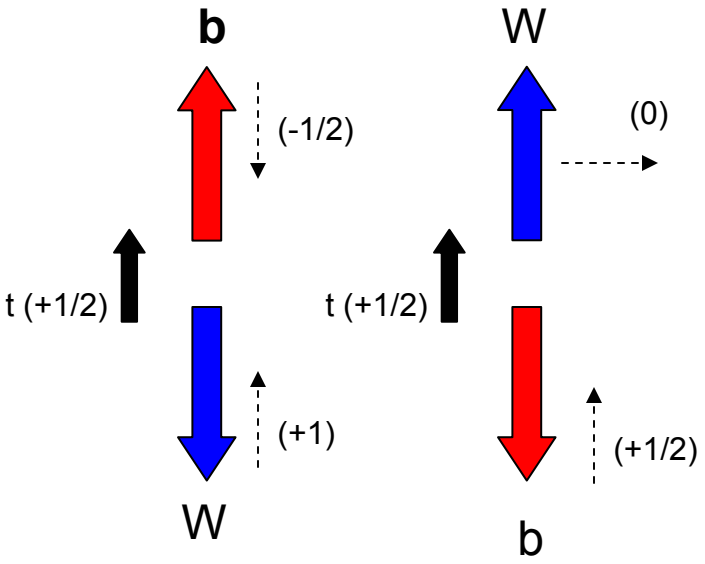


$$\frac{-ig}{2\sqrt{2}}\bar{t}\gamma^{\mu}(1-\gamma^{5})V_{tb}bW_{\mu}$$

- The nature of the tbW vertex have not yet been studied accurately.
- Sensitive to anomalous (non-SM) couplings.

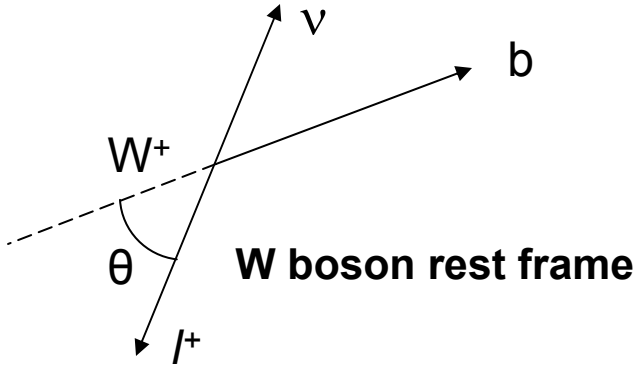
- In the SM, top quarks decay as left-handed fermions through the V-A weak interaction.

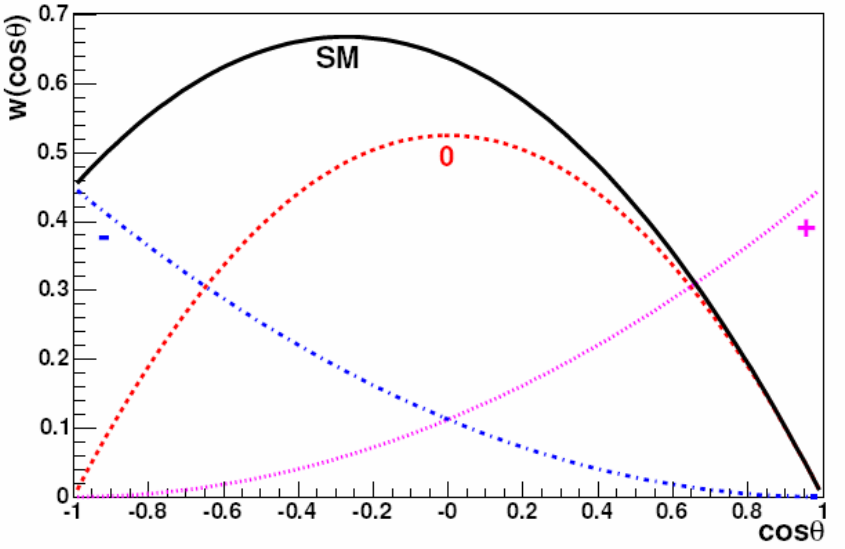
- In the limit of massless b quark, the V-A coupling at the tbW vertex requires that the b quark in top decays is produced left handed.
- Angular momentum conservation only allows left-handed and longitudinal W helicity configurations.



Top quark rest frame

Polarized W Boson Decay





• The angular distribution of the helicity states of the W boson is described by the angle between the lepton and the original W momentum in the W rest frame.

A measurement of the W helicity probes the underlying weak interaction of the top decay.

Observation of a V+A charged-current interaction would indicate physics beyond the SM.

$$w(\cos\theta) = f_- \frac{3}{8}(1-\cos\theta)^2 + f_0 \frac{3}{8}(1-\cos^2\theta) + f_+ \frac{3}{8}(1+\cos\theta)^2$$

$$f_- = \frac{2\frac{m_W^2}{m_T^2}}{1+2\frac{m_W^2}{m_T^2}} \approx 0.30 \qquad f_0 = \frac{1}{1+2\frac{m_W^2}{m_T^2}} \approx 0.70 \qquad f_+ \approx 0$$

Previous Run 1 measurements:
- CDF: $f_0 = 0.91 \pm 0.37 \pm 0.13$, $f_+ = 0.11 \pm 0.15$ (stat)
- DØ: $f_0 = 0.56 \pm 0.31 \pm 0.07$

We want to measure f_+.

Outline of the Analysis

- Event selection.
  - Lepton plus jets kinematic pre-selection:
    - W+jets.
    - $t\bar{t}$.
    - Multi-jets.
  - b quark-jet tagging.

Two separate analyses:
- Topological
- b-tagging.

- Top quark identification:
  - Topological likelihood $\Rightarrow$ separate top quark from W+jets.
  - Kinematic constraint fit $\Rightarrow$ reconstruct four-vectors of final state particles.

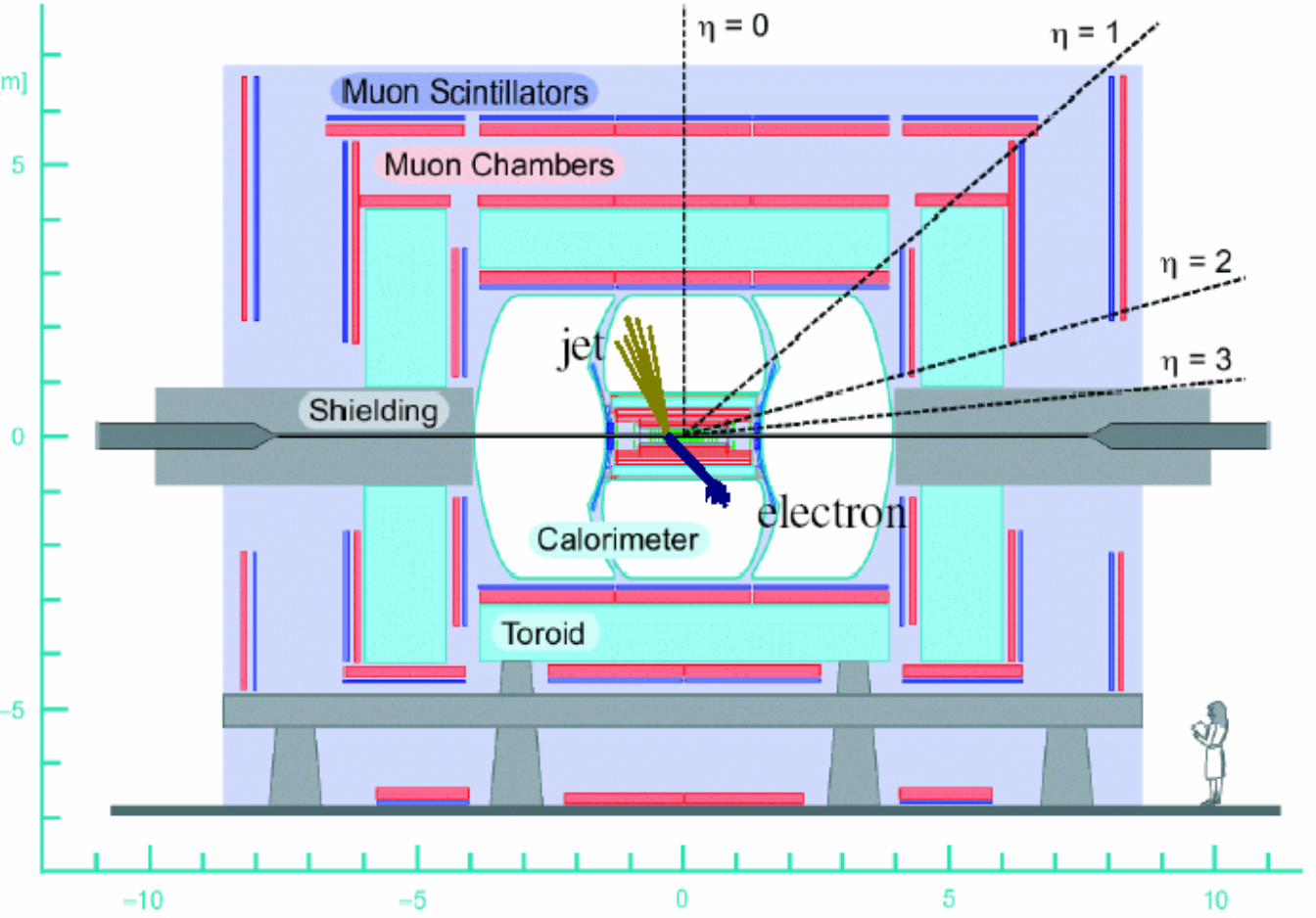
- Measure *cos(θ)* for each selected event.

- Compare the measured distribution of *cos(θ)* to its expectation from background and signal templates with different V+A fractions (f_0 is fixed at its SM value).

- **Determine the most likely value of f_+:**
  - Binned likelihood fit to cos(θ) distribution.
  - Confidence interval for f_+.

Integrated Luminosity:
- e+jets: 168.7 pb^{-1}.
- μ+jets 158.4 pb^{-1}.

The DØ Detector



Tracking:

- Silicon and Fiber tracker.
- 2T magnetic field.
- Central and Forward pre-shower.

Calorimeter:

- New electronics.

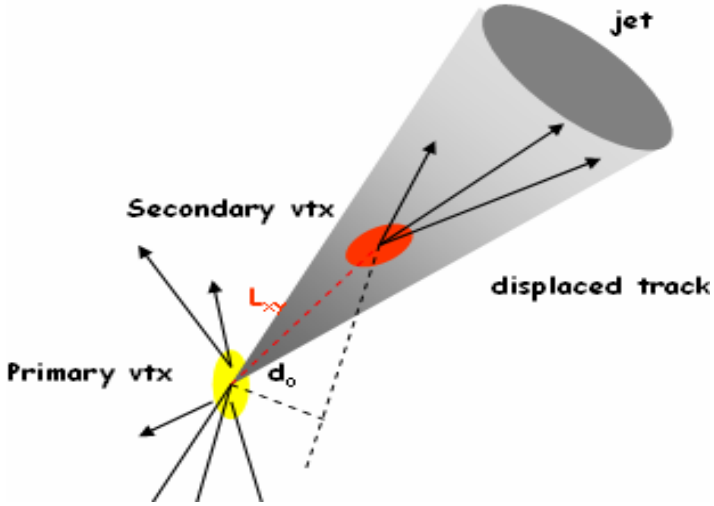
Muon detector:

- 1.8 T Toroid.
- $|\eta| < 2$.

Event Pre-Selection

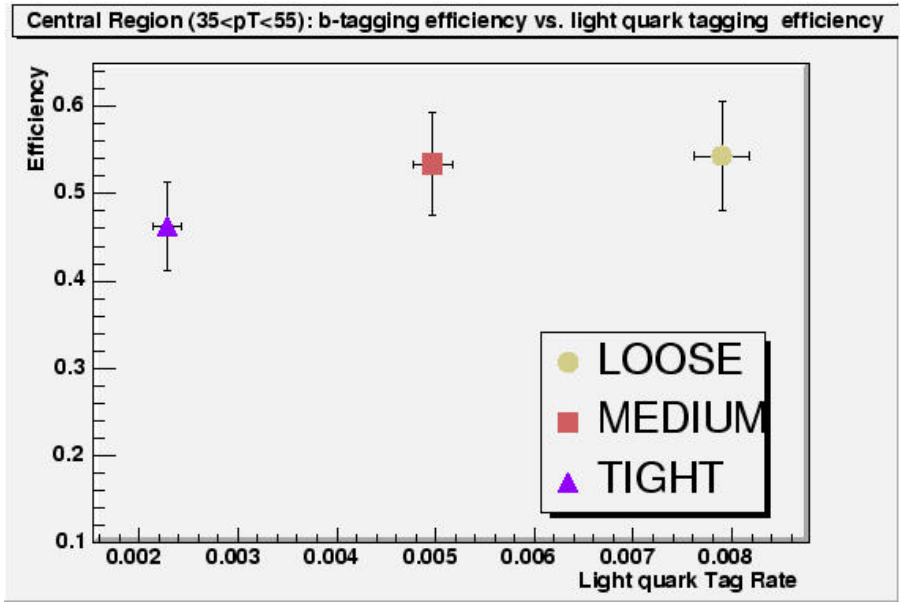
Kinematics Selection:

- ≥1 isolated e, p_T>20GeV, |η|<1.1
or 1 isolated μ, p_T>20 GeV, |η|<2.0.
- Missing transverse energy (E_T^{mis})>20 GeV.
- 4 or more jets, p_T>15 GeV, |η|<2.5.



b-tag analysis: ≥1 b-tagged jet
(Secondary Vertex Algorithm)

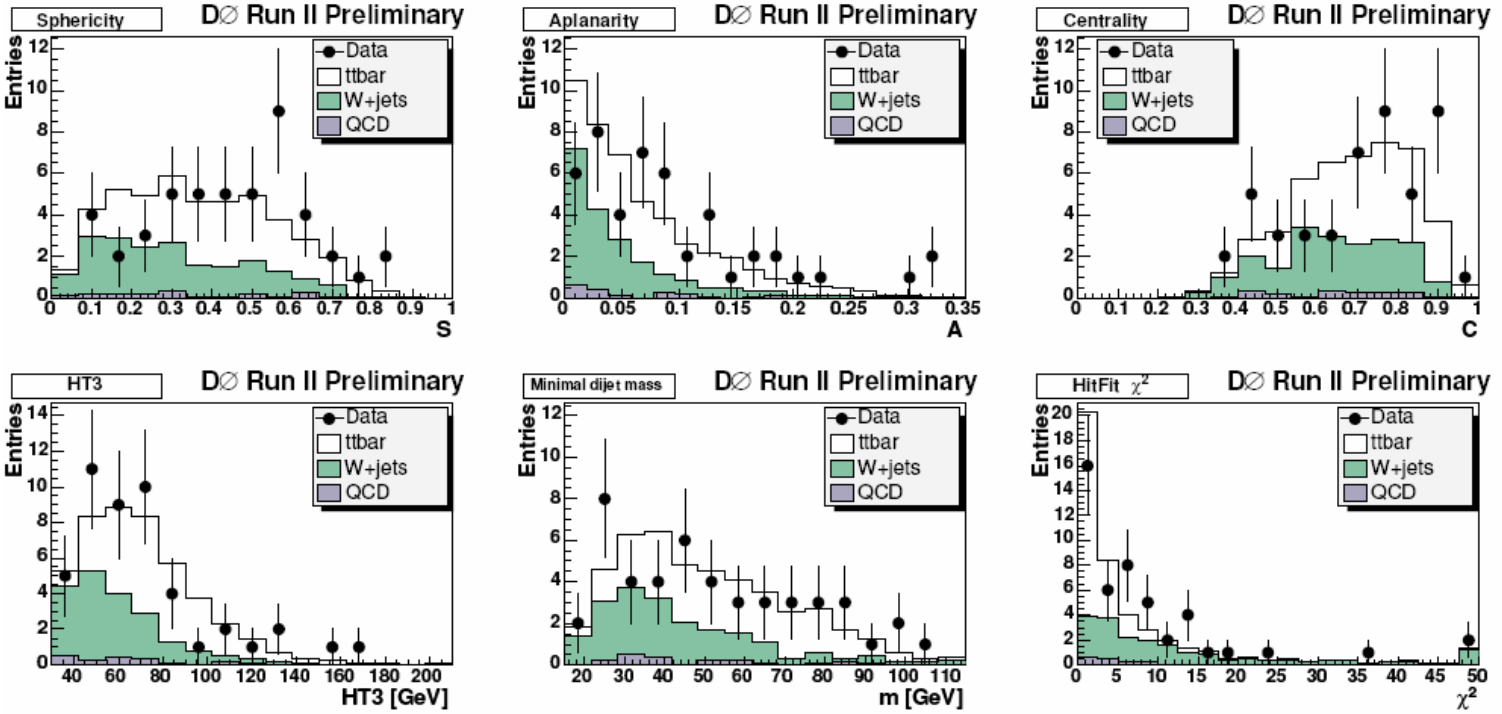
- Find track-jets
- Find secondary vertices within jets.
- Select significantly displaced vertices.



Topological Selection

Both analyses use a 6-variable topological likelihood to discriminate $t\bar{t}$ from W+jets events.

- Top quark events are more spherically and centrally produced and have larger transverse energy than W+jets.
- Optimized to maximize the statistical significance between V+A and V-A decays.
- Likelihood cut efficiency is almost independent of f_+.

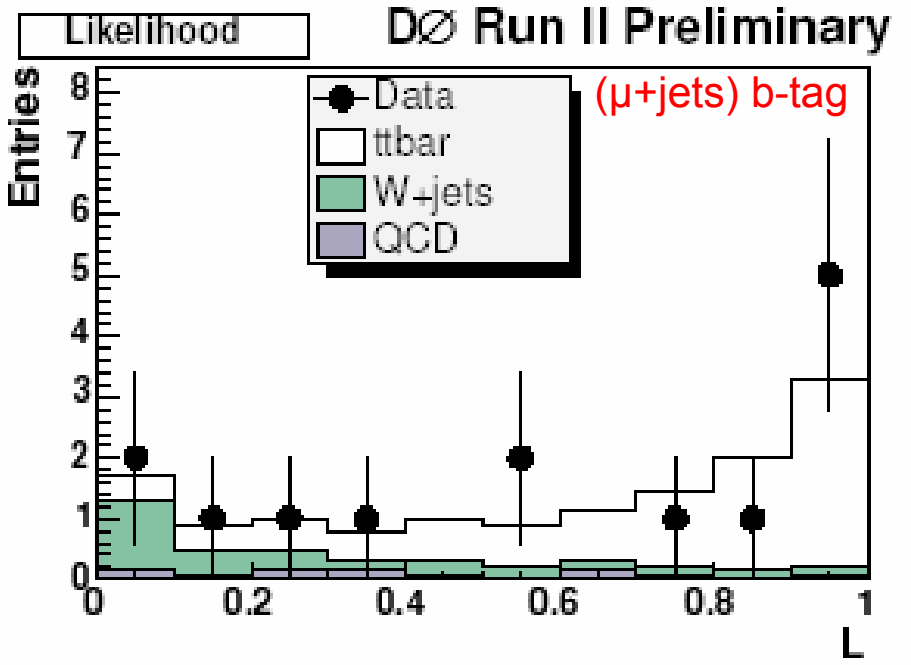


Signal and Background Discrimination

The number of multi-jet events is determined by making use of the different rate (with respect to W+jets or $t\bar{t}$) to fake leptons.

The number of $t\bar{t}$ and W+jets events is extracted by making use of the likelihood discriminant distribution:

- By performing a fit (b-tag analysis)
- By performing a cut and using the cut efficiency determined in Monte Carlo (Topological analysis).



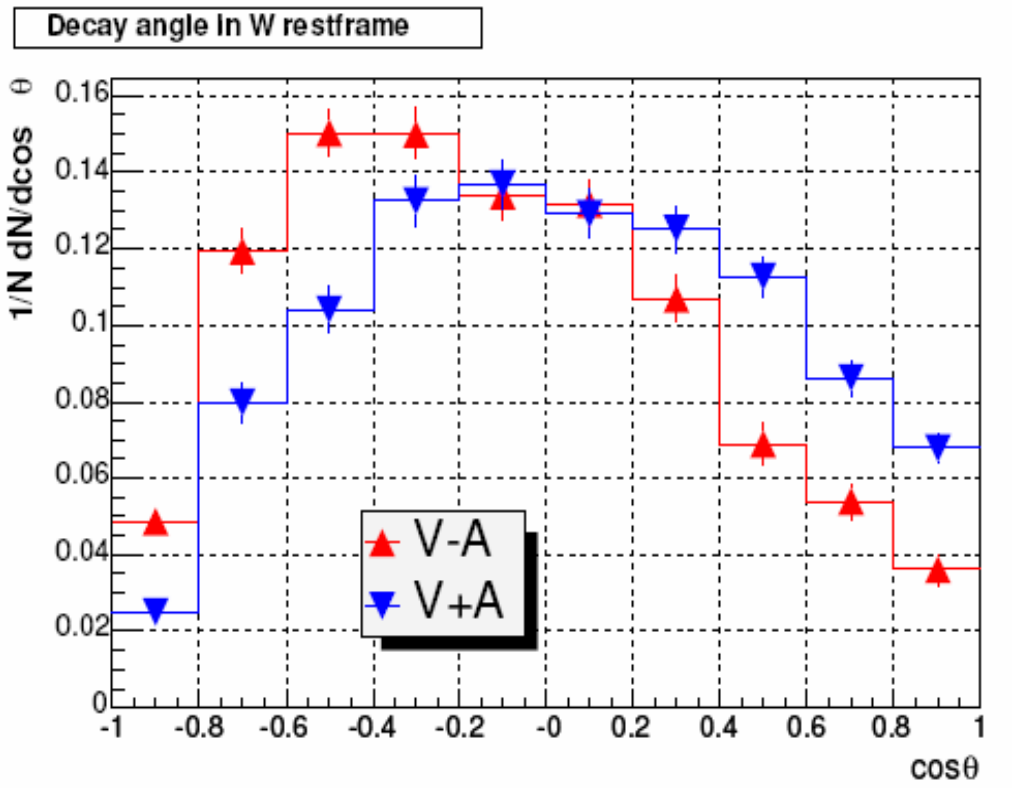
b-tag selection: L>0.1 (μ) L>0.3 (e)

Channel	$t\bar{t}$	W+jets	Multi-jets
μ+jets	9.6 ± 2.7	2.0 ± 1.4	0.7 ± 0.4
e+jets	14.2 ± 3.4	6.6 ± 1.8	0.6 ± 0.3

Topological selection: L>0.6

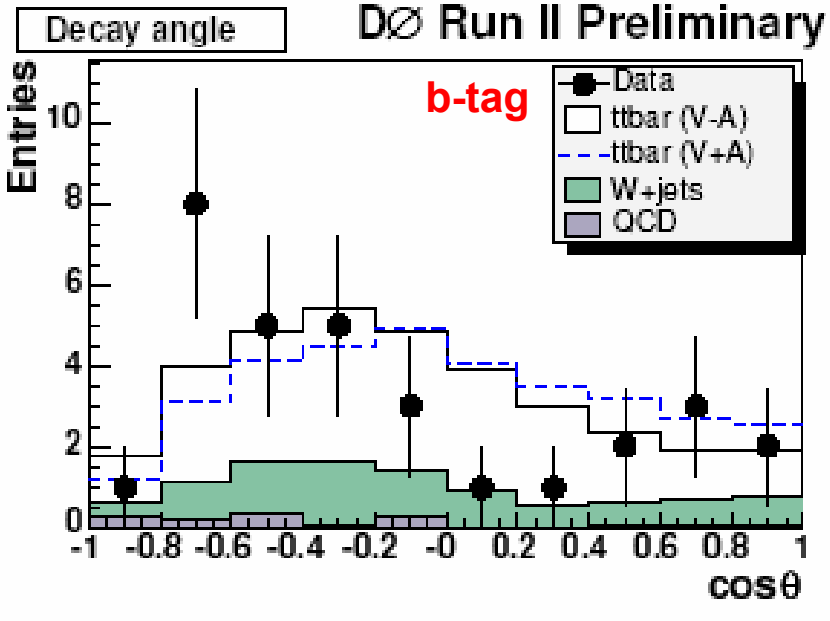
Channel	$t\bar{t}$	W+jets	Multi-jets
μ+jets	11.3 ± 1.3	17.6 ± 1.2	2.1 ± 0.5
e+jets	25.9 ± 1.5	20.3 ± 1.5	2.7 ± 0.5

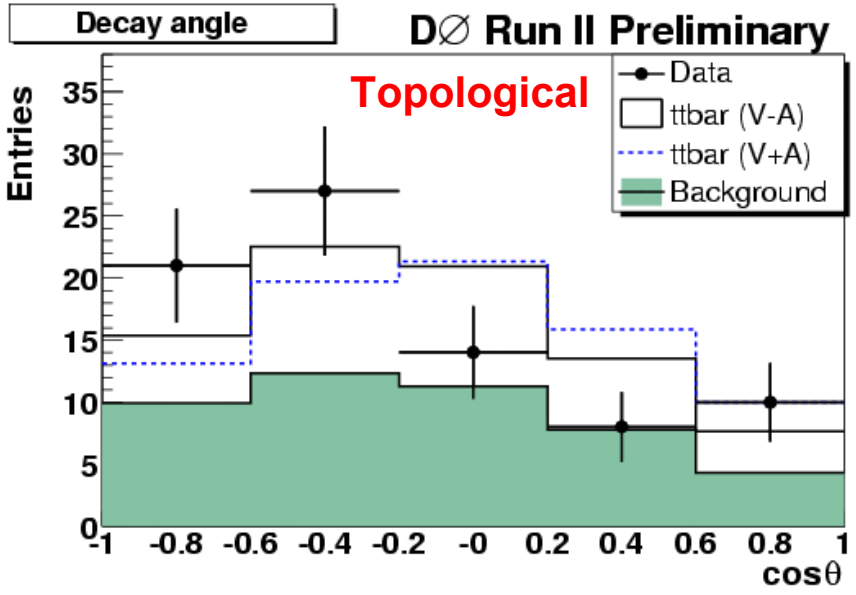
Cos(θ) Templates



- **Kinematic constraint fit:**
  - Reconstruct four vectors of all particles. Minimize χ^2 defined as:
  - $\chi^2 = (\vec{x} - \vec{x}_M) G^{-1} (\vec{x} - \vec{x}_M)^T$
  - m(jj) = m(lν) = m_W = 80.4GeV.
  - m(jjl) = m(ljν) = m_t = 175.0GeV.
  - 12 possible jet-parton assignments → Choose solution with lowest χ^2.
- **Signal *cos(θ)* templates:**
  - f_+= 0.0 .. 0.3 (maximum possible value) in steps of 0.05.
  - f_0 fixed at 0.7.
- **Background templates:**
  - W+jets (from Monte Carlo).
  - Multijets (from data, with reversed isolation criteria for leptons)

W Helicity Measurement





f_+ is extracted by means of a binned Poisson maximum likelihood fit using the decay angle templates for Multi-jets, W+jets, and the signal templates.

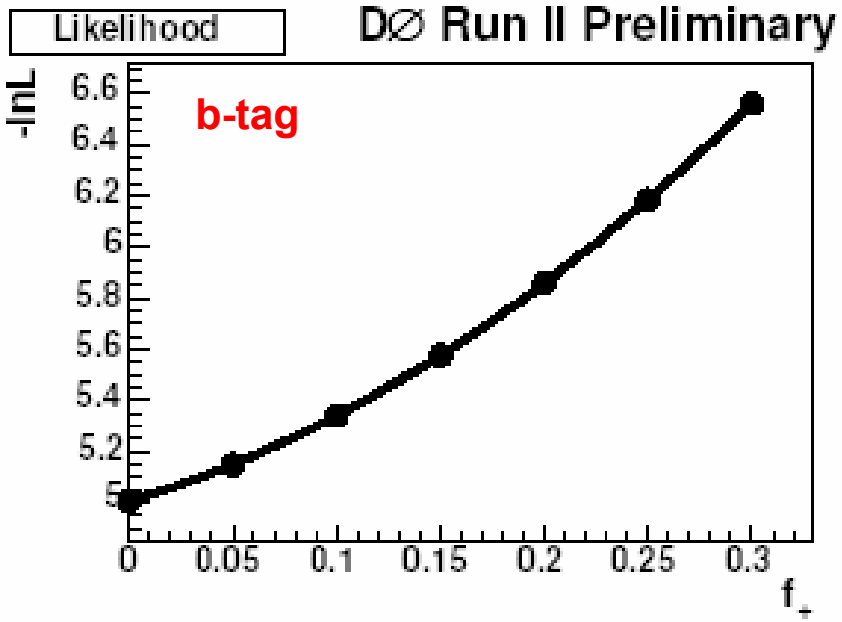
The likelihood is built by multiplying the Poisson probabilities of each template bin, for each value of f_+.

Results and Limit Calculation

- Determine a confidence interval with 90% confidence level for f_+ using a Bayesian technique.
- Find upper limit with 90% C.L. since the minimum of –ln(L) lies outside the physically-allowed range.

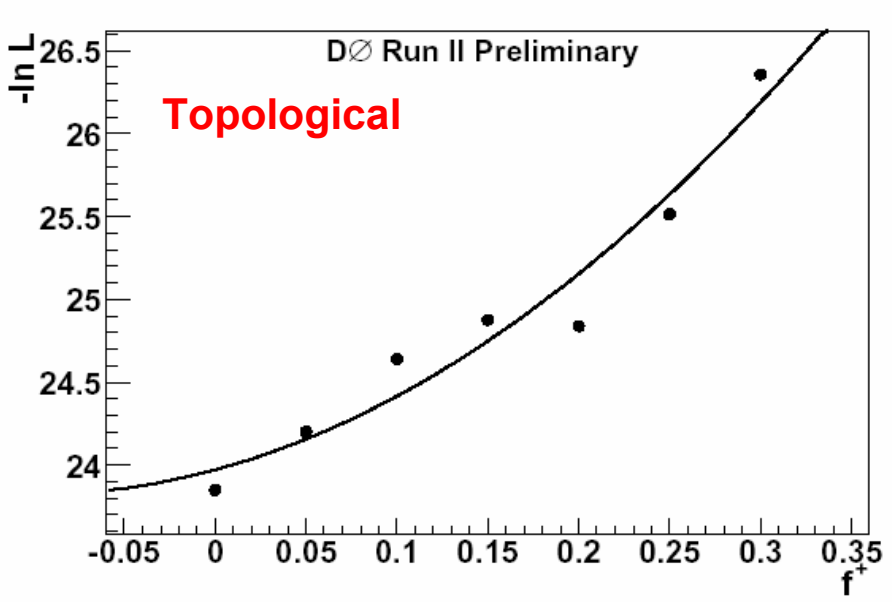
Prior:

$$\pi(f_+) = \begin{cases} 1 & 0 \le f_+ \le 0.3 \\ 0 & f_+ < 0 \; or \; f_+ > 0.3 \end{cases}$$



Central value: $f_+ = -0.13 \pm 0.23$ (stat)

$f_+ < 0.24$ (90% C.L.) including syst.



Central value: $f_+ = -0.11 \pm 0.19$ (stat)

$f_+ < 0.24$ (90% C.L.) including syst.

Systematic Uncertainties

b-tag

Source	Uncertainty on f_+
Top mass	0.06
Underlying Event	0.06
Jet energy scale	0.07
Likelihood fit (number of signal and background events)	0.02 (μ) 0.01 (e)
Monte Carlo statistics	0.01
W+jets heavy flavor composition	0.01
Total	**0.11**

Topological

Source	Uncertainty on f_+
Top mass	0.11
Jet energy scale	0.04
ttbar model	0.05
W+jets model	0.08
Total	**0.15**

Factor of ~1.5-2 smaller than statistical errors.

- Systematic uncertainties are incorporated in the limit calculation by convoluting a Gaussian function –of width given by the total systematic uncertainty- with the likelihood.
- The magnitude of each systematic uncertainty is estimated by running ensemble tests:
  - Create toy experiments with modified templates.
  - Likelihood fit using standard templates.
  - Observe shift in the maximum of the likelihood.

Summary

- First DØ Measurement of the V+A component in the tbW vertex using topological and lifetime b-tagging techniques.
- Analysis based on the decay angle between the lepton and the original W momentum in the W boson rest frame.

$f_+ < 0.24$ (90% C.L.) Topological.
$f_+ < 0.24$ (90% C.L.) b-tag.

Results including systematic uncertainties.

- Preliminary results are in agreement with the SM prediction.
- Two analyses will be combined into a single result.
- Set the ground for more precise measurement:

  Expect improvements from larger data sample (~0.5 fb^{-1} by the end of 2004) and by the use of more sophisticated techniques being developed.